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Perspective

Physics-based dynamic simulation opportunities with digital twins

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ABSTRACT

This paper aims to provide a viewpoint on the exploitation of physics-based dynamic simulation in product development and discrete manufacturing products. The dynamics models can be represented with computationally light models when the product and its dynamics are well known and thereby analyzing the performance e.g., with AI methods rapidly and accurately. The recent developments with methodologies, sensor development, measuring techniques and increased computing capacity are making the simulation world closer to reality and the ability for real-time operation simulations paralleled to the real system. This enables the exploitation of the digital twin paradigm at full capacity together with high-maturity digital twin models.

1. Introduction

1.1 Physics-based simulation

In advanced high-technology countries, such as Finland, the utilization of physics-based simulation has long been employed. Machine manufacturers have the most information about the product and its behavior, thus the utilization of physics-based simulation enables them to predict the actual performance in the early design phase when the machine is built. This allows for tailoring the products more to customer needs and assessing the requirements that influence the machine performance. Thereby, the possibility to meet the customer requirements can be considered at a higher level than without the physics-based simulation.

2. Digital twins

With the recent advancement in the theme of digital twins, the interest in the utilization of existing simulation models with the actual product through its lifecycle has been of interest. Specifically, real-time capable simulation tools are attractive, since they can be utilized in cases where a human is operating the machine e.g., in mobile heavy machinery applications [1]. The physics-based simulation has been supporting machine design and other disciplines since the analytical equations were formulated. Currently, the digital transformation is rapidly making the demand for simulation technology even higher. Especially the digital twin paradigm and its development have been the driver for the clarification and definition of the physics-based simulation and its role and potential for business [1]. Figure 1 depicts an example of a high-speed electric machine rotor, where the dynamics are defined by the high-speed rotor and a conceptual example of the digital twin solution to it.

While working in a computer environment and exchanging information in a digital format enables us to assess the information from various points. It thereby enables the development of systematic methods for analyzing and assessing the information, for example for decision-making purposes, with high accuracy. Current trends, such as sustainability and energy efficiency, are driving the development further and developing computationally efficient means of simulation.

Dynamics simulation has been in a central role in product development in large machines, for example, off-highway vehicles for decades. The dynamics can be assessed with computationally efficient models and can be even used in real-time applications for assessing the machine's performance when a human is acting as an operator. Thus, the recent development in algorithm development especially in the computationally efficient dynamics calculation methods has progressed rapidly. For example, multibody system dynamics is used in many industrial applications as a basic methodology for conducting the virtual design for the dynamical behavior of the product. In most cases, it means e.g. avoiding the resonance frequencies while operating the application.

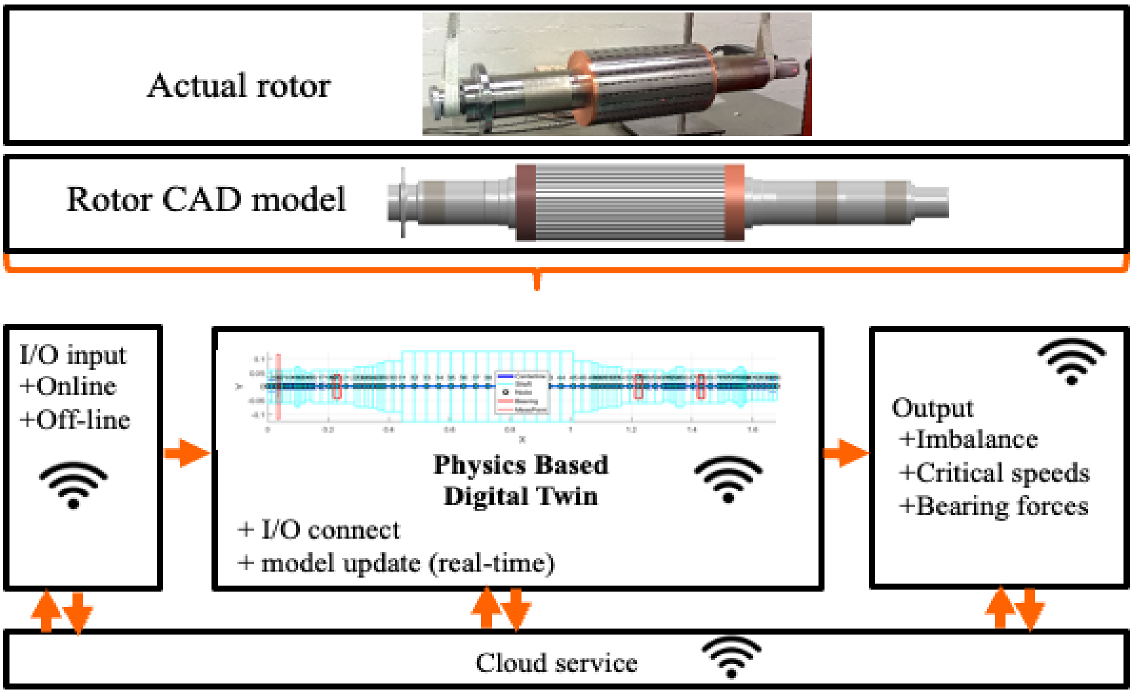

Figure 1. Example case with a high-speed rotating rotor

The combination of physics-based simulation and measured data enables computationally efficient methods for creating neural networks e.g., for fault identification tasks and the transferability of the developed neural networks is of the essence i.e., not solely for single-purpose utilization but also beyond it to another similar type of products [2].

One approach to utilizing physics-based simulation is to utilize the validated computational models as a base for investigating the parameters and their sensitivity. It is worth noting that a deep understanding of the machine should be defined prior to exploring the parameters and their sensitivity to the dynamics. In these cases, the measured data from real machines is of importance, as that is used to validate and verify the simulation models. Figure 2 depicts a conceptual solution for creating the identification software with design information.

Fundamentals of dynamics can be captured with simple models, see for example [3]. The 3 DOF model computational time is approximately 10 seconds solved in the frequency domain, the 27 DOF model solved in the time domain takes 8 hours, and the full measurements approximately one week, and the resonance frequency should be avoided to ensure the safe operation. However, it should be well known what the application and expected behavior are to decide when for example a simplified model is justified to be utilized. Accordingly, the constant development of computationally efficient simulation models is ongoing, (refer to e.g., [4]). The dynamics are a product of the product mass and stiffness properties. When identifying changes in the systems the parameters which influence the mass or stiffness have the most effect on the system i.e., increased flexibility of structures is not a wanted phenomenon in the system. The system-level understanding is important to have in the virtual world as different configurations can be benchmarked prior to manufacturing the first prototype.

In addition, current products include more software for control, and with the accurate virtual product, software development can be initiated prior to the first physical prototype being built. While neural networks have also been active in the focus of research, the need for labeled data is the main prerequisite for accurate and efficient neural network creation, especially in supervised learning. The physics-based simulation models can produce data for that purpose. Especially including non-idealities and faults in the datasets can be created with ease [5].

The research related to efficient and accurate simulation techniques is in progress, which is beneficial for the labeled data generation with a computer [4, 6]. Therefore it is expected that the simulation is capable of merging tighter with the real world more effectively. Accordingly, the benefits of both approaches can be used to generate an understanding of the applications. With the active development of the modeling techniques and requirements for measurements becoming clearer, the gap between simulation models and reality is getting smaller. For example, the recent development in the utilization of Kalman filters and connecting them with computationally efficient simulation methods [7] is a promising step to closing the gap between simulation and the real world.

3. Conclusion

The physics-based simulation has several possibilities to enhance the product lifecycle from early design to end-of-life. Simulation enables rapid design iterations to explore the behavior as it serves as the virtual object and simultaneously it helps to align and structure different stakeholders' viewpoints and information in a clear and quantitive perspective. Currently, the exploitation strategies for different types of companies are under active research.

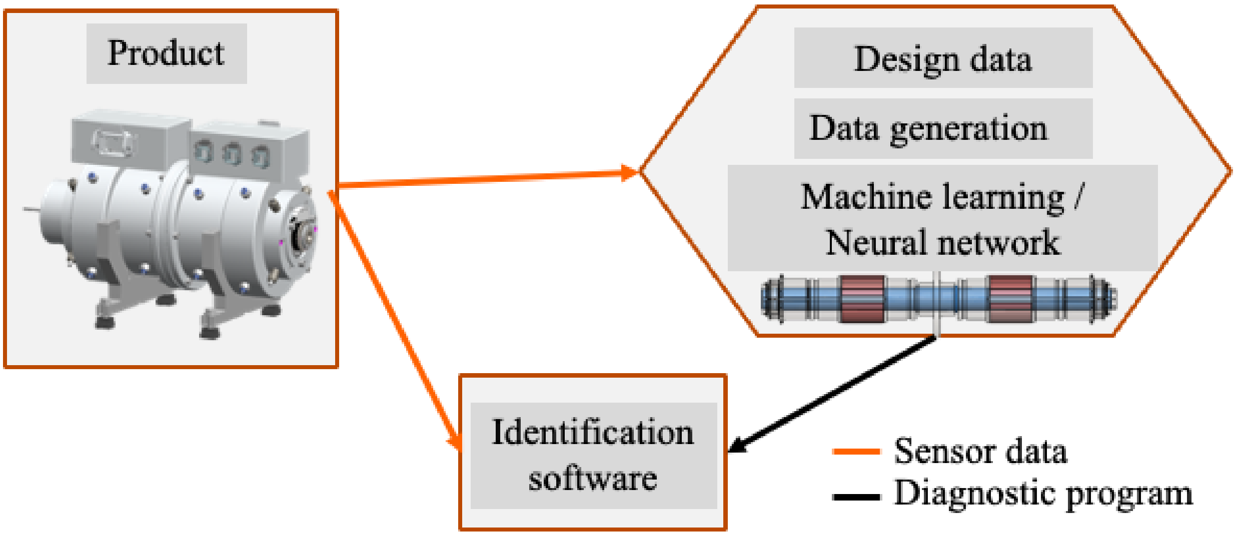

Figure 2. Utilization of design data for identification software building

The virtual product and its exploitation are especially beneficial as the inertia related to tests is minimum when compared to physical prototyping. Simultaneously, the decision based on virtual products should be well validated to align the behavior with the real environment.

Ethical issue

The authors are aware of and comply with best practices in publication ethics, specifically with regard to authorship (avoidance of guest authorship), dual submission, manipulation of figures, competing interests, and compliance with policies on research ethics. The authors adhere to publication requirements that the submitted work is original and has not been published elsewhere.

Data availability statement

Data sharing is not applicable to this article as no datasets were generated or analyzed during the current study.

Conflict of interest

The author declares no potential conflict of interest.

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